Describing the optical properties of astronomical dust analogs through numerical techniques

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From Dust to Galaxies, Paris, 06/30/2011







- Introduction
 - The interstellar medium in the infrared
 - The quest for the optical constants
- - Previous work
 - Methodology
- - . Experimental data and appelland
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- - 🚤 Conclusions
 - Future perspectives



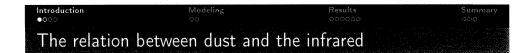
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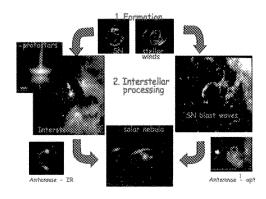


Figure: Formation, processing, and evolution of interstellar dust (Rinehart et al., 2008)

Interstellar dust:

- plays a role in the birth of stars
- precursor material for the formation of planets
- hides astronomical objects from our view

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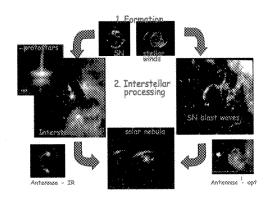


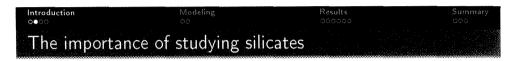
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Infrared observations are crucial to understanding the origins of the universe.

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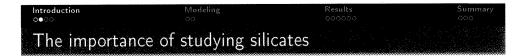
Spectral features attributed to:

- silicates
- carbonaceous grains
- PAHs

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Constraints on chemical and physical structure

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Constraints on chemical and physical structure

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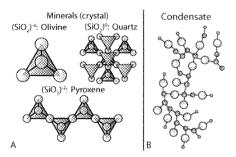


Figure: A) Silicates on Earth are ordered solids. B) In space their structure is chaotic. (Adapted from Rinehart et al., 2008)

The optical constants as primary parameters

Definition

Complex refractive index m = n + ik

- The refractive index *n* determines the velocity of constant-phase waves.
- \bullet The extinction index k determines the attenuation of the wave as it propagates through the medium.

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Dielectric constant $\varepsilon = (n + ik)^2 = \varepsilon' + i\varepsilon''$

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Problem: the optical constants are not directly measurable.

• Experimental apparatus and measurements

- Development of the model of the computation of the optical constants as a function of wavelength and temperature
- Validation through application to societies as a
- a Analysis and interpretation of post-processed data
- a Population of a line of optical properties to the far intraced regime.



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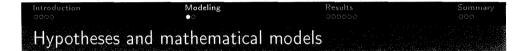


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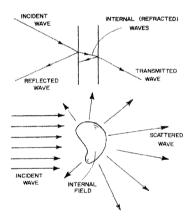


Figure: Analogy between scattering by a particle and transmission-reflection-absorption by a slab (Bohren and Huffman, 1983)

Transmission-line approximation

- One-laver slab modes
 (Botteen and Hilliman
 1963)
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Figure: Analogy between scattering by a particle and transmission-reflection-absorption by a slab (Bohren and Huffman, 1983)

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- One-layer slab model (Bohren and Huffman, 1983)
- Beer's law (Halpern et al., 1986)

Transition modes

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Hypotheses and mathematical models

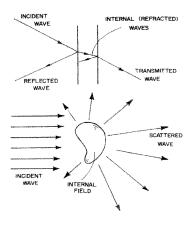


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Transition modes

Lorentz model

Adoption

 Mulliwell-Garden formets (Markett Garden), 1994).

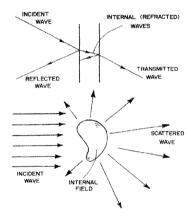


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Mixtures

 Maxwell-Garnett formula (Maxwell Garnett, 1904)

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Results 000000 Summary 000

Constrained minimization as main working tool

Definition (Least-Squares Nonlinear Fit)

$$\min_{DOFs} \chi_m^2 = \min_{DOFs} \frac{1}{N} \sum_{j=1}^{N} \left[T \left(DOFs, \lambda_j \right) - T_{measured} \right]^2$$

$$DOF_{min} \leq DOF \leq DOF_{max}$$

N = number of data points

 λ = wavelength

Initial condition \rightarrow Fig. $> DOS_2 \rightarrow \emptyset$ $\begin{cases}
-1, R, A \\
-6, k,
\end{cases}$ (2)



Constrained minimization as main working tool

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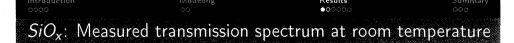
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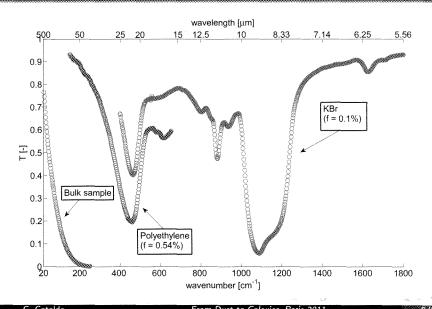
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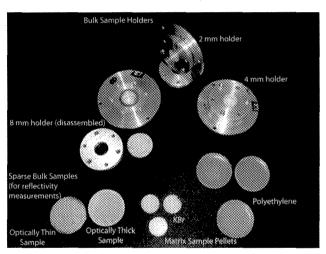


Figure: Various sample preparations are needed to cover the wide frequency range (Rinehart, Cataldo, et al., *Applied Optics*, in press).

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Each sample preparation has a different optical depth, which allows us to obtain transmission values in the range of 0.2-0.8 as needed to determine the optical constants to high accuracy.

| Sample type | Spectral coverage $[\mu m]$ |
|--------------|-----------------------------|
| 8-mm | 300 — 1000 |
| 4-mm | 100 - 500 |
| 2-mm | 100 - 350 |
| Polyethylene | 15 - 100 |
| KBr | 1 - 25 |

SiO_x : How to extract the optical constants (bulk samples)

Beer's law

$$T = (1 - R)^2 \exp\left(-\alpha h\right)$$

$$R = \frac{(n+1)^2 + k^2}{(n+1)^2 + k^2}$$

$$T = T(a, a, b)$$

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Results

Summary

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$$k = \frac{\alpha}{2\omega} = \frac{\partial}{2\omega} \left(\frac{\omega}{2\pi}\right)^{b-1}$$

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Results ○•000 Summary 000

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SiO_x : How to extract the optical constants (mixtures)

Maxwell-Garnett formula

$$\varepsilon_{\it eff} = \varepsilon_{\it eff} \left(f, \varepsilon_{\it b}, \varepsilon_{\it i} \right)$$

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Results ○○●○○ Summary

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Lorentz model

$$\varepsilon_{i} = (n + ik)^{2} = \varepsilon_{i,\infty} + \sum_{j=1}^{M} b_{m} \frac{\omega_{p,j}^{2}}{\omega_{0,j}^{2} - \omega^{2} - i\omega\nu_{j}} = \varepsilon_{i}(\text{OOFs}, \omega)$$

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Modified Lorentz model (Sihvola, 1999)

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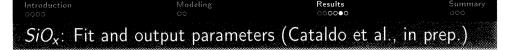
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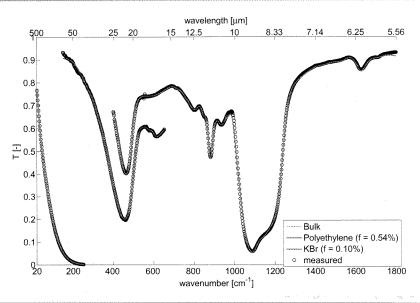
Modified Lorentz model (Sihvola, 1999)

$$\varepsilon_{\text{eff}} = \varepsilon_{\text{eff}} (f, \varepsilon_{b}, DOFs_{i}, \omega)$$

One-layer slab model (averaged)

$$T = T[f, \varepsilon_b, (4M+1)DOFs_i, \omega]$$





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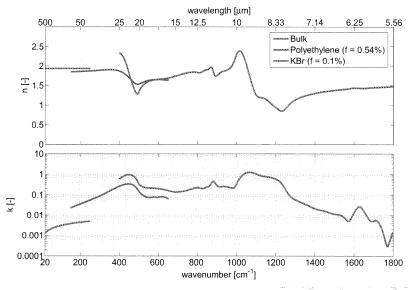
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 SiO_{x} : Fit and output parameters

| | | Bulk (4-mm) | Polyethylene | KBr |
|----------------|---------|----------------------|-----------------------|----------------------|
| DOFs | | 3 | 53 (13 LOs) | 153 (38 LOs) |
| Residual | average | 0.32 | 0.62 | 0.25 |
| ΔT [%] | maximum | 2.68 | 3.93 | 1.47 |
| χ_m^2 | - | $2.55 \cdot 10^{-5}$ | $11.12 \cdot 10^{-5}$ | $1.29 \cdot 10^{-5}$ |
| σ | | 0.005 | 0.012 | 0.008 |
| χ^2 | | 109.89 | 239.81 | 146.26 |
| χ^2_{ν} | | 0.93 | 1.15 | 0.25 |



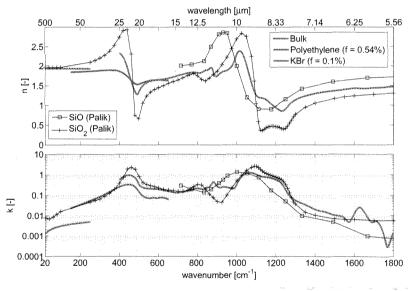
SiO_x : The optical constants in the FIR and MIR



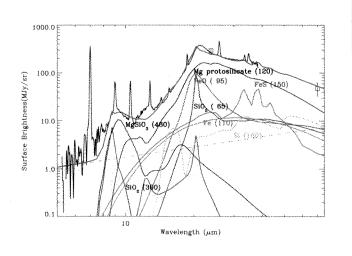
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SiO_x : The optical constants in the FIR and MIR



SiO_x : The optical constants in the FIR and MIR



(Adapted from Rho et al., 2008)

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Our sample description

| | Advantages | Disadvantages | |
|-------------|--|-------------------------------------|--|
| Bulk sample | n consistent with other measurements | n not well constrained | |
| Bull sumple | a = 0.003, b = 1.552 (Agladze et al., 95;) | Need for data at longer wavelengths | |
| | n-k independent from filling fraction | n-k dependent on matrix | |
| Mixture | $x \approx 1.5$ | Fine-tuning | |
| | DOFs well constrained | of starting guess | |
| | Outputs for mix and particles | Uncertainty in measurements | |

• Measured reflectance data (TOP PRIORITY)

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- Development of more sophisticated models.
 - Markett was the paneliers. Control My rich solutions. (Kinzer, Cataldo et al., in prop.)
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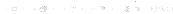
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 - Scattering
 - Multiple-layered structures
 - Unparalleled faces and roughness

Application to the opening aboretory data and designation





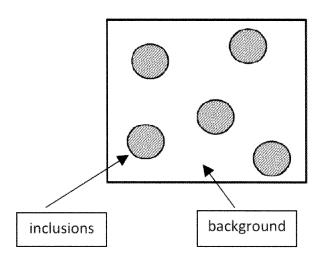
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Thanks! Questions?



The effective medium structure





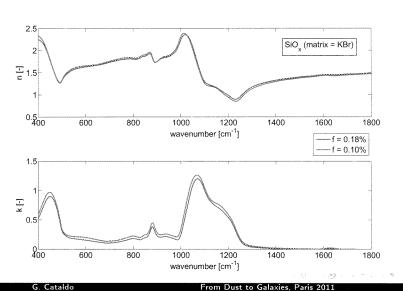
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Appendix

The optical constants as a function of filling fraction

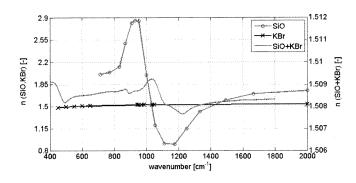




Appendi

The optical constants for the $SiO_x - KBr$ mixture





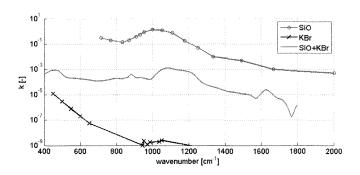
(Rinehart, Cataldo, et al., Applied Optics, in press)

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Appendi:

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